PV MODULE MAXIMUM POWER POINT TRACKER(MPPT) USING MICROCONTROLLER

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Date :

Specially dedicated with lots of loves to

My beloved parent

Ismail Salim & Samidah Ab Samad

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ABSTRACT

PV Module Maximum Power Point Tracker(MPPT) , is a photovoltaic system that uses the photovoltaic array as a source of electrical power supply. Every photovoltaic (PV) array has an optimum operating point, called the maximum power point, which varies depending on cell temperature, the insolation level and array voltage. The function of MPPT is needed to operate the PV array at its maximum power point. The design of a Maximum Peak Power Tracking (MPPT) is proposed utilizing a boost-converter topology. Solar panel voltage and current are continuously monitored by a closed-loop microprocessor based control system, and the duty cycle of the boost converter continuously adjusted to extract maximum power. The design consists of a PV array, DC-DC Boost converters (also known as step-up converters) and a control section that uses the PIC16F877A microcontroller. The control section obtains the information from the PV array through microcontroller's Analog to Digital Converter (ADC) ports and hence to perform)the pulse width modulation (PWM) to the converter through its Digital to Analog Converter (DAC) ports. Many such algorithms have been proposed. However, one particular algorithm, the perturb-and-observe (P&O) method, claimed by many in the literature to be inferior to others, continues to be by far the most widely used method in commercial PV MPPT's.

(Keywords: Boost Converter, Pulse Width Modulation,PIC16F877A)

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LIST OF ABBREVIATIONS

PWM	-	Pulse Width Modulation
MPPT	-	Maximum Power Point Tracker
PV	-	Photovoltaic
DC	-	Direct Current
D,d	-	Duty Ratio
DCM	-	Discontinuous Current Mode
CCM	-	Continuous Current Mode
MOSFET	-	Metal Oxide Silicon Field Effect Transistor

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Maximum Power Point Tracker (MPPT) is an electronic system operates the Photovoltaic (PV) modules in a manner that allows the PV modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that "physically moves" the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power.

The problem faced by MPPT is it not perfectly delivered the output voltage as stated, since the outputs of PV system are depends on the temperature, irradiation, and the load electrical characteristic. So, that's why MPPT is needed to be implementing in the PV system to maximize the PV array output voltage.

1.2 Overview of Photovoltaic (PV)

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sunlight directly into electricity. Photovoltaic are generally known as a method for generating solar power by using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays to convert energy from the sun into electricity. In the simple words the photons from sunlight knock electrons into a higher state of energy, creating electricity. The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a batterylead acid.

PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, and the maximum power point (MPP) occurs at the knee of the curve as shown in Figure 1.0, where the resistance is equal to the negative of the differential resistance ($V/I = -dV/dI$).

1.3 Overview of Maximum Power Point Tracker (MPPT)

A maximum power point tracker (MPPT) is a high efficiency DC to DC converter which functions as an optimal electrical load for a photovoltaic (PV) cell, most commonly for a solar panel or array, and converts the power to a voltage or current level which is more suitable to whatever load the system is designed to drive. PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. Maximum power point trackers utilize some type of control circuit or logic and algorithm to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

In short , photovoltaic (PV) arrays are used to provide energy and MPPT are used to correct the variations in the current-voltage characteristics of the solar cells. The Figure 1.0 is an idealized curve with no deformations due to cell damage or bypass diodes kicking in. The point on the current-voltage (I-V) curve of a solar module under illumination, where the product of current and voltage is maximum (P_{max}, measured in watts). The points on the I and V scales which describe this curve point are named I_{mp} (current at maximum power) and V_{mp} (voltage at maximum power.).

For a typical silicon cell panel, the maximum power point (MPP) is about 17 volts for a 36-cell configuration. For the array to be able to delivered the maximum possible amount of power, either the operating voltage or current needs to be carefully controlled. This maximum power point is seldom located at the same voltage the main system is operating at, and even if the two were equal initially, the power point would quickly move as lighting conditions and temperature change (varied under the ambient condition). Hence, a device is needed that finds the maximum power point and converts that voltage to a voltage equal to the system voltage.

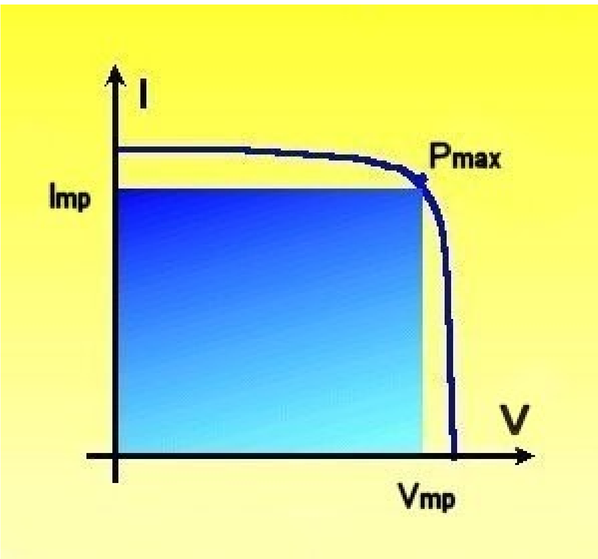

Figure 1.0 : MPP characteristic

1.4 **Objectives**

i. Implementation of microcontroller in the MPPT system.
   - The used of the microcontroller to control the D (duty cycle for the boost converter) by the algorithm that has been choosen.

   .

ii. The operation of the PV module should be forced to operate at maximum power point under varying ambient condition.

1.5 Scopes of Project

This project relates to a method and a device for implementing the method that tracks the optimal maximum power point in a system that supplies power from a direct-current power source, such as that generated by a solar cell array (photovoltaic generator)

i. The choosing of DC-DC converter based on the desired output voltage from the MPPT in term to ensure the PV module will operate at the maximum point.
   - The DC-CC converter that will be used in this project is the Boost Converter. The power MOSFET in the circuit act as the switching element towards the converter due to its capability in sustaining the high level current and voltage. The PIC will act as the controller of the circuit by giving the signal to the power MOSFET for its switching mode (On and off) to produce the desired voltage.

ii. The implementation of microcontroller (PIC16F877A) to produce PWM.

- PIC16F877A is used to generate PWM by using crystal 20MHz, the maximum PWM frequency value can be generated by PIC16F877A is 208.3 kHz. The duty cycle can be start from 0 to 0.99. [5]

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 MPPT

MPPT is a circuit that allows extracting Maximum Power Point from PV array independently from the variation of its electrical characteristic that is function of the operative condition (temperature, illumination, and aging). The optimization of the delivered power is delivered by controlling current through the array or the voltage across it, with the best working point (MPP) of the power characteristic.[1]

Specifically the Power Point Tracker is a high frequency DC to DC converter. They take the DC input from the solar panels, change it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the loads. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with very high efficiency transformers and small components.

2.2 Boost Converter

The need of converter in the MPPT system is to maximize the varied input of DC voltage. In term of maximized the output voltage by step up the input voltage the boost converter is ideally to be choose in the MPPT design compared to the Buck converter since the Boost converter can always track the maximum power point.[3] By referring to the input of the both topologies the Buck converter input voltage is always greater or equal to its output voltage so the output panel must exceed the battery voltage for power to flow. The maximum power point of 12V commercial PV module is above 13V for most combinations of insolation and temperature. So buck converter can operate at the MPP undermost but not at all condition. While for the Boost converter input voltage must lie between the zero and output voltage so that's why, Boost converter will always be able to operate at the panel's MPP. In term of simplicity a buck converter with a MOSFET switch still requires an additional diode or MOSFET's to block the reverse current flow when the panel voltage drops below the battery voltage, as an advantages of Boost converter naturally it has this devices as part of its structure , which eliminates an additional source of voltage drop and power loss.

A boost converter has been employed in this application to regulate the power output to the load. It consists of an inductor, a logic level, Power MOSFET switch, a Schotky diode and capacitors. Figure 2.1 shows a typical connection of a boost converter. The basic Boost converter containing at least two semiconductor switches (a diode and a transistor) and one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple..

A 15 to 18volt from the solar panel will be the target operation point of the solar panel. In this case we will extract a current of 4.6 Amp from the device, which will then give us a maximum power from the PV array.

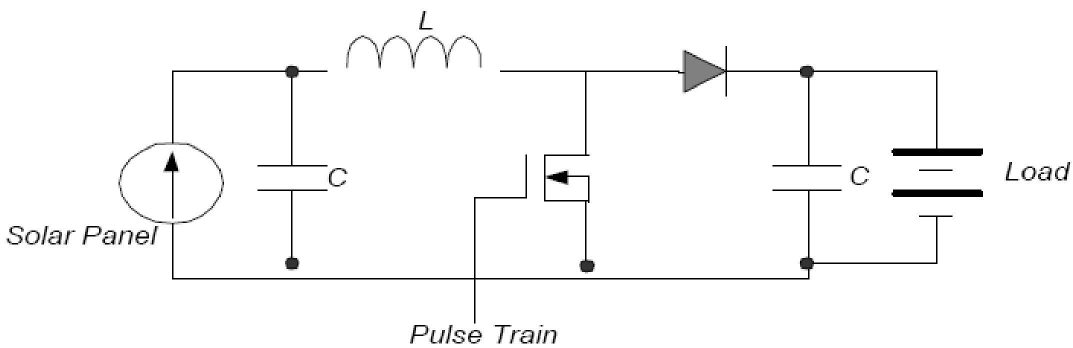

Figure 2.1 : Boost Circuit

2.2.1 Operation of Boost Converter

As known, a boost converter is capable of providing an output voltage that is greater than the input voltage. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy like a resistor), when being discharged, it acts as an energy source (like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages. The basic principle of a Boost converter consists in 2 distinct states as in Figure 2.2 and 2.3.

- In figure 2.2 at the On-state,, resulting in an increase in the inductor current;
- In Figure 2.3 at the Off-state, the Transistor (switch) is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. This result in transferring the energy accumulated during the On-state into the capacitor.
- The input current is discontinuous, stepping between a very high inductor current and 0. The large ripple usually requires a large input bypass capacitor to reduce the source impedance.

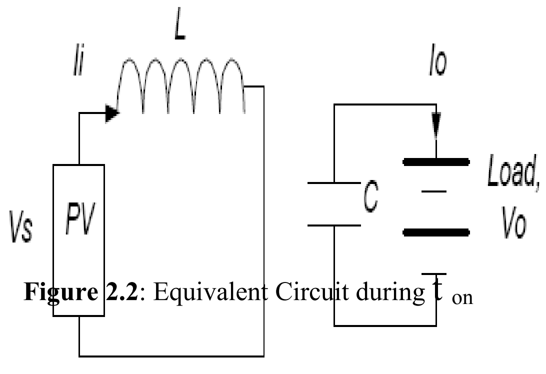

Figure 2.2: Equivalent Circuit during t_{on}

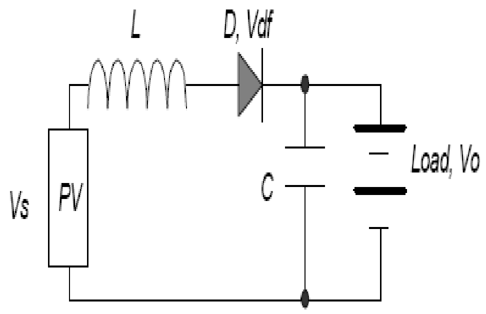

Figure 2.3: Equivalent Circuit during t_{off}

The operation of a boost converter can be divided into two modes the Continuous Current Mode and the Discontinuous Current Mode. Depending on the switching actions of the switching device (like MOSFET).

During the Continuous Current Mode the current through the inductor (I_L) never falls to zero. Figure 2.4 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behavior) operating in steady conditions. During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

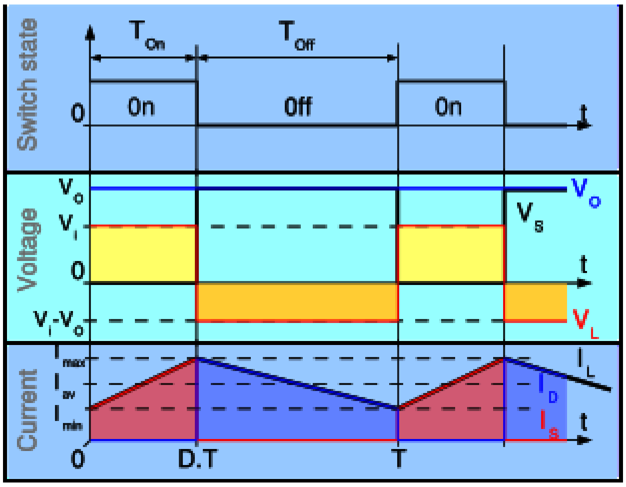

Figure 2.4: Waveforms of current and voltage in a boost converter operating in continuous mode

$$\Delta I_L / \Delta t = V_i / L \quad (1)$$

At the end of the On-state, the increase of I_L is given by:

$$\Delta I_{L\,on} = (Vi .D. T) / L \quad (2)$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (S is always on). During the Off-state, the switch S is open, so the inductor current flows through the load. By considering there was zero voltage drops in the diode, and a capacitor large enough for its voltage to remain constant, the derivation of I_L is:

$$\mathbf{V_i - V_o = L\, dI_L / dt} \qquad (3)$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta \mathbf{I}_{\mathbf{L\,off}} = \mathbf{(Vi\text{-}Vo)(1\text{-}D)\ T] / L} \qquad (4)$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$\mathbf{E = 0.5L\ .\ I_L^{\,2}} \qquad (5)$$

Therefore, the inductor current has to be the same at the beginning and the end of the commutation cycle. This can be written as

$$\Delta \mathbf{I}_{\mathbf{L\,on}} + \Delta \mathbf{I}_{\mathbf{L\,off}} = \mathbf{0} \qquad (6)$$

Substituting $\Delta \mathbf{I}_{\mathbf{L\,on}}$ and $\Delta \mathbf{I}_{\mathbf{L\,off}}$ by their expressions yields:

$$\Delta \mathbf{I}_{\mathbf{L\,on}} + \Delta \mathbf{I}_{\mathbf{L\,off}} = [(Vi\ .D.T) / L] + [(Vi\ \text{-}Vo).(1\text{-}D)T] / L = 0 \qquad (7)$$

This can be written as:

$$\mathbf{V_o / V_i = 1/(1\text{-}D)} \qquad (8)$$

Which in turns reveals the duty cycle to be:

$$\mathbf{D = 1\text{-}\ (V_i / V_o)} \qquad (9)$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

While during the discontinuous mode occurs, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle see waveforms in Figure 2.5. The difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L\,max}$ (at t=D.T) is

$$\mathbf{I_{L\,MAX} = (V_i.\ D.T) / L} \qquad (10)$$

During the off-period, I_L falls to zero after δ.T:

$$\mathbf{I_{L\,MAX} + [\ (Vi\ Vo).\ \Delta.T] / L = 0} \qquad (11)$$

Using the two previous equations, δ is:

$$\mathbf{\delta = (\ Vi\ .D) / (Vo-Vi)} \qquad (12)$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$\mathbf{I_o = I_D = (I_{L\,MAX} / 2)\ .\ \delta} \qquad (13)$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$\mathbf{I_o = (Vi^2\ .\ D^2\ .\ T) / 2L\ (V_o - V_i)} \qquad (14)$$

Therefore, the output voltage gain can be written as :

$$\mathbf{V_o / V_i = 1 + [(V_i\,.\,D^2.T) / (2L\,.I_o)} \qquad (15)$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current.

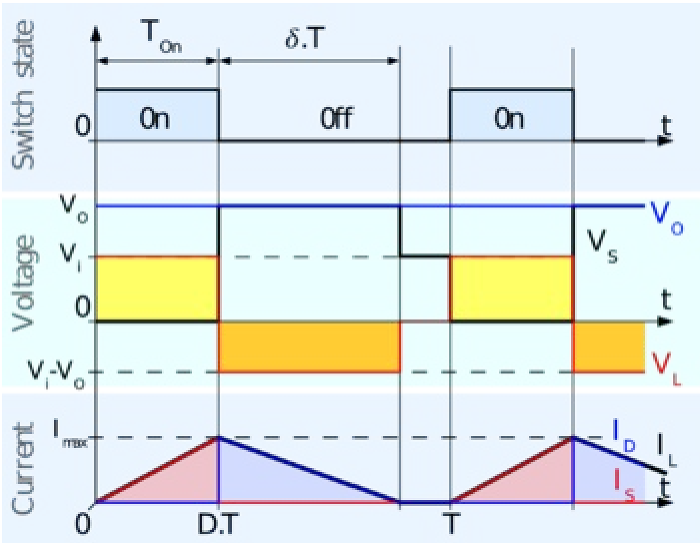

Figure 2.5: Waveforms of current and voltage in a boost converter operating in Discontinuous mode

2.3 MOSFET Driver

A gate voltage ($V_{G)}$ is always needed to control the switching of the MOSFET, enabling it to behave as a switch in the boost converter. This voltage V_G, directly affects the turn on and turns off time delay of the MOSFET as a switching device. As a result, a drive circuit will be needed to enhance the performance of the MOSFET, thus the overall efficiency of the MPPT circuit. The important characteristics of the MOSFET is to turn it on, the gate terminal value at least 10 volts greater than the source terminal (about 4 volts for logic level MOSFET's).[5]

The circuit driver should be able to supply a reasonable current to ensure the stray capacitance can be charged up as soon as possible. Since the large stray capacitance between the gate and the terminal is one of the important characteristic of MOSFET. Because of this characteristic the capacitance needs to be charged up before the gate voltage reaches the desired voltage.